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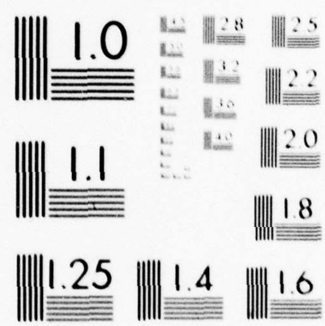
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RADIO COMMUNICATION UTILIZING THE BASE OF A STRIATED BARIUM PLASMA

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July 1978

Topical Report for Period April 1978—July 1978

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Barium Cloud
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In conjunction with the DNA barium releases, Avefria I and II, an experiment was undertaken to determine if radio communication was possible off the base of a striated plasma created by these barium releases. A transmitting station was set up to broadcast a steady signal at two HF frequencies toward the base of the barium striations and two receiving stations listened for signal returns on the two frequencies. (The chosen geometry prevented reflections off the sides of the barium cloud from affecting the experiment.) One station heard

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20. ABSTRACT (Continued)

substantial returns while the other heard nothing. Data from the first station provide an estimate of the reflection cross sections for the base of the striated barium cloud. The negative result from the second station arises partly from limited sensitivity of equipment but the upper limit on cross section was less than that seen from the first station. This suggests a directional character for the signal reflected from the base of the cloud.

SUMMARY

It has been proposed that radio communication off the base of striated plasma clouds from high-altitude nuclear explosions may provide an alternate mode to give additional reliability to military communications systems. In order to test this possibility, the base of a striated barium cloud was used as a reflection region for an HF communications link.

Using a transmitting station nearly under the base of a cloud and two receiving stations located a few hundred km from the transmitting site, a dramatic enhancement for about one minute at one receiving station was seen at 14 MHz for two different barium releases. Tests at 7 MHz showed lesser enhancement due to greater background noise but probably represent greater signal levels. Estimates of cross section range from 20 km^2 to .02 km^2 depending upon frequency, event, and receiving station. The negative results at the second receiving station suggest, but do not prove, that the striated structure of the barium cloud provides a differential cross section which is dependent upon scattering geometry relative to the magnetic field.

The data strongly suggest that the source of scattered radio signals was the overdense ionized barium cloud and not any artifact such as the rocket itself or the shock front resulting from the explosions.

This experiment has demonstrated that the base of a structured barium release can support a mode of radio communication not otherwise available, which suggests that the nuclear plume base may support similar

modes. However, in view of the evident differences between barium clouds and high-altitude nuclear events, the correspondence between their communications modes must be considered with care.

PREFACE

Many members of the Mission Research Corporation staff contributed to this project including Steve Chavin, Bill White, Blair Sawyer, Ralph Kilb, Steve Gutsche, Bill Hanna, Warren Schlueter, and others. We would like to thank the United States Forest Service and Federal Aviation Administration for providing facilities for our use. Finally, this experiment would not have been possible without the cooperation and assistance of those managing Project Avefria, including especially Morris Pongratz of LASL.

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SECTION 1
INTRODUCTION

Radio communication in the HF and VHF regions over long distances on the earth's surface is generally possible only by reflection or scattering of the radio waves. (Ground wave and line of sight communications are usually limited to short distances.) Many reflection and scattering phenomena are known and routinely utilized. Normal ionospheric reflections are by far the most important but scattering from sporadic E, meteor trails, tropospheric discontinuities and a variety of other phenomena can be important at times.

In a military situation involving the use of nuclear weapons, many of these standard reflection and scattering modes may be severely degraded to the point of being useless due to D-layer absorption of the radio signal. However, the detonation of high-altitude nuclear explosions also produces magnetic field-aligned plasma striations which themselves can scatter radio signals. Communication systems capable of utilizing these bomb modes may function in situations where standard equipment will not.

The experiment described in this paper was designed to investigate the possibility of reflecting radio signals between pairs of stations off the base or ends of plasma striations created by a barium cloud. (Ends occur either at the furthest extent of plasma diffusion along the magnetic field lines or where the plasma is consumed by the atmosphere.) Such a communication mode was proposed in Reference 1. Communications off the base of striations rather than off the sides is of interest because, over CONUS, the reflection geometry strongly favors these reflections. Useful

reflections off the sides of striations produced in CONUS are possible only in special cases because of the steep dip angle of the magnetic field.

Barium releases are utilized for this experiment because they produce striations that are as close to those produced by high-altitude nuclear explosions as is currently practical. There are notable differences between a barium release and a nuclear explosion. The peak electron concentration is about two orders of magnitude less than in the nuclear case, the striations produced are probably smaller in size, and the chemical processes degrading the striations are different. Because of the lower electron concentrations in a barium release, this experiment utilizes lower radio frequencies than would be appropriate in the nuclear case. The smaller physical size of barium clouds produces smaller cross sections and therefore lower received signal levels than would be expected in the nuclear case. The different chemistry of barium clouds may produce differently shaped ends for barium striations and therefore a different directional character of the scattered radio signal.

Evidence of radio wave scattering by striated plasmas is plentiful both in the nuclear and barium cases. However, most of this pertains to reflection from the sides of the striations.[2] Data indicating reflection from the base of the striations are sparse.[3] Some appear to exist in the nuclear case and are being investigated in a separate effort. None is known to exist for barium clouds. This experiment was undertaken to look for such evidence.

SECTION 2
EXPERIMENT

This experiment consisted of three radio stations employing amateur radio type equipment. One station, consisting of two transmitters, was located in Tonopah, Nevada and two receiving stations, each with two receivers, were located in Ely, Nevada and Santa Barbara, California. The barium releases themselves occurred just SE of Tonopah at an altitude of about 200 km. Figure 1 shows the geographic layout, while Tables 1, 2 and 3 summarize the important parameters for the three locations.

Tonopah was chosen for the transmitting station because it was close to the release and looked almost directly at the bases of the magnetic field-aligned striations. If the barium cloud was to reflect radio waves from the transmitter to the receivers, it could only do so via the base of the cloud. Reflections from plasma occur in a mirror-like fashion with the angle of incidence equaling the angle of reflection for frequencies less than the plasma frequency. Because of the geometry chosen for this experiment, reflections between the transmitter and receivers off the sides of the cloud were impossible.

The transmitting station at Tonopah used two Heathkit transmitters and two Heathkit linear amplifiers. Operating without modulation on a frequency of 7.175 MHz (λ = 41.78 m), a Heathkit SB101 driver was used to feed a Heathkit SB220 linear amplifier. This combination produced 590 watts of RF output power which was, in turn, fed into the center of a half wave dipole antenna suspended horizontally 9.1 m or 1/4 wave above dry ground. Similarly, a Heathkit HW101 driver and SB200 linear amplifier were used without modulation at 14.1 MHz (λ = 21.2 km) to produce 550 and 500 watts of RF on the first

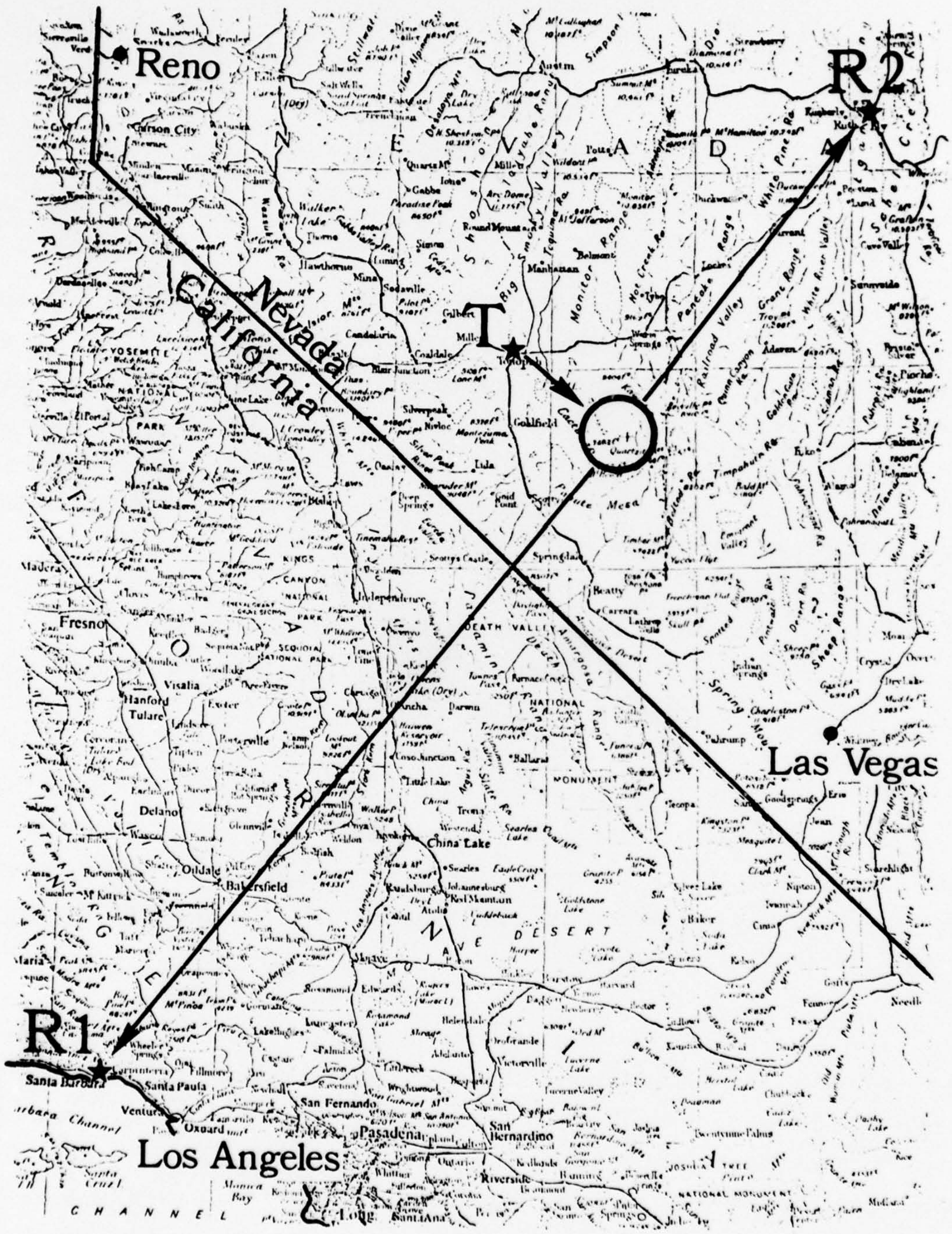

Figure 1. Arrangement of receiving and transmitting stations relative to the barium releases.

Table 1. Santa Barbara receiver parameters. Location was 34"31'N, 119°49'W, at an elevation of .8 km. Antenna orientation was horizontal with broadside at 45° E of N.

	AVEFRIA I		AVEFRIA II	
Frequency	7.175 MHz	14.1 MHz	7.175 MHz	14.1 MHz
Wavelength (m)	41.78	21.26	41.78	21.26
Receiver	Yaesu FT101EX	Heath SB303	FT101EX	SB303
Bandwidth (Hz)	500	500	500	500
Ant. Dipole Height (m)	10	10	10	10
Range R_R(km)	507	507	515	515
Azimuth (deg)	40.7	40.7	40.5	40.5
Elevation (deg)	20.2	20.2	19.4	19.4
Ant. Gain G_R	1.5 dB	6 dB	1.5 dB	6 dB
Line Loss L_R (dB)	-1.8 dB	-3 dB	-1.8 dB	-3 dB
VSWR	1.1:1	1.4:1	1.1:1	1.4:1
Enhancement $V_{R_{max}}$	8 μV	.2 μV	<10 μV	1.9 μV

Table 2. Ely, Nevada receiver parameters. Location was 39°18'N, 114°50.5'W, at an elevation of 1.9 km. Antenna orientation was horizontal with broadside at -152° W of N.

	AVEFRIA I		AVEFRIA II	
Frequency	7.175 MHz	14.1 MHz	7.175 MHz	14.1 MHz
Wavelength (m)	41.78	21.26	41.78	21.26
Receiver	Swan 350	Heath SB100	SB100	Swan 350
Bandwidth (Hz)	2800	2800	2800	2800
Dipole Ant. Height(m)	7.9	7.0	7.9	7.0
Range R_R(km)	303	303	293	293
Azimuth (deg)	-144	-144	-144	-144
Elevation (deg)	38.2	38.2	39.1	39.1
Ant. Gain G_R	3 dB	4.5 dB	3 dB	4.5 dB
Line Loss L_R	-.5 dB	-.7 dB	-.5 dB	-.7 dB
Enhancement $V_{R_{max}}$	<15 μV	<5 μV	<15 μV	<1.5 μV

Table 3. Tonopah, Nevada transmitter parameters. Location was at 38°3'N, 117°9'W, at an elevation of 1.8 km. Antenna orientation was horizontal with broadside at 110° E of N.

	AVEFRIA I		AVEFRIA II	
Frequency	7.175 MHz	14.1 MHz	7.175 MHz	14.1 MHz
Wavelength (m)	41.78	21.26	41.78	21.26
Transmitter	Heath SB101	Heath HW101	SB101	HW101
Amplifier	Heath SB220	Heath SB200	SB220	SB200
Dipole Ant Height (m)	9.1	7.6	9.1	4.0
Range R_T(km)	209	209	206	206
Azimuth(deg)	126	126	118	118
Elevation(deg)	66.2	66.2	65.9	65.9
Scattering Angle to SB	115°	115°	117°	117°
Scattering Angle to Ely	127°	127°	125°	125°
VSWR	1.4:1	1.2:1	1.4:1	1.2:1
Ant Gain G_T	4.5 dB	3.0 dB	4.5 dB	4.0 dB
Line Loss L_T	-.5 dB	-.7 dB	-.5 dB	-.7 dB
Power Output P_T	590 watts	550 watts	590 watts	500 watts

and second barium releases respectively. This signal was fed into a separate horizontal half wave dipole located 7.6 m above the ground on the first release and 4.0 m on the second. The height of the antenna was changed between releases to give a higher and more reliably known gain in the direction of the release. Both the 7 and 14 MHz antennas were oriented such that their main beams pointed toward the release location. A 15 m length of RG59 coaxial cable was used between each transmitter and antenna. The VSWR of each system was kept low by appropriate tuning of the antennas.

The receiving station in Santa Barbara used similar half wave horizontal dipole antennas connected to Heathkit SB303 and Yaesu FT101EX receivers. Both antennas pointed toward the barium releases and were about 10 meters above dry ground. The one operated at 7.175 MHz was thus a quarter wave high and the one at 14.1 MHz was a half wave high. A longer run of 60 meters of RG59 coaxial cable was necessary to connect the antennas and receivers. The VSWR was measured and found to be low for this station also. Both receivers had CW filters which limited the received bandwidth to about 500 Hz and thus reduced background noise.

The receiving station in Ely was similar to the one in Santa Barbara. It used a Swan 350 and a Heathkit SB100 receiver. The Swan was used on 7.175 MHz for the first release and, then, because it appeared to give better results than the Heathkit on 14.1 MHz, was switched to this frequency for the second release. Again, half wave, center-fed, horizontal dipoles pointing at the release were used for the antennas and 15 m of RG59 coaxial cable connected the receivers to the antennas. The 7.175 MHz antenna was 7.9 m or $\lambda/5$ high while the 14.1 MHz antenna was $\lambda/3$ high. It was not possible to measure the VSWR at this station but it was believed to be low. Neither receiver had a CW filter so the basic receiver bandwidth of 2.8 kHz had to be used. This resulted in somewhat greater noise levels.

The barium releases themselves (Avefria I and II) were conducted over the Nevada Test Site southeast of Tonopah. Rockets carried 1.5 kg of barium to an altitude of about 200 km just prior to dawn on 8 May and 18 May 1978. The barium was released using a shaped charged configuration in an attempt to produce prompt striations. Table 4 summarizes the important parameters of the releases.

Table 4. Barium release parameters.

	AVEFRIA I	AVEFRIA II
Date	8 May 1978	18 May 1978
Time	04:44:00 PDT	04:35:00 PDT
Altitude	193.36 km	190.35 km
Latitude	37.61813°N	37.69845°N
Longitude	116.39925°W	116.33302°W
Magnetic Dip Angle	63.4°	63.4°
Magnetic Declination (E of N)	15.8°	15.8°

The basic operating procedure involved the simultaneous transmission of unmodulated carriers at the two frequencies for a period of 20 seconds commencing on the minute and half minute. A 10 second period of silence was maintained between these transmissions to clearly mark the transmissions and to allow the transmitters to cool down. (Transmitters of this type cannot maintain a 100 percent duty cycle.) Immediately preceding the barium releases and for about a minute thereafter, the transmitters were left on so that maximum information about the releases would be obtained.

At the receiving stations, the strength of the received signal was constantly monitored by chart recorders wired to the AGC circuits of the receivers. These AGC circuits produce a voltage that is monotonically related to the strength of the incoming signal. By using calibrated inputs to the receivers, it was possible to fully calibrate the response displayed by the chart recorders. While AGC circuits are not ideal for a measurement of actual received signal strength because of limited sensitivity as well as various rise and decay constants built into the circuitry, they served admirably in the present context.

Figures 2 and 3 show an annotated version of the raw strip chart recordings from Santa Barbara for the first and second barium releases, Avefria I and II respectively. These charts show the strength of the incoming signal versus time for both 7.175 MHz (bottom trace) and 14.1 MHz (top trace). (Because the chart recorder pens are offset slightly, the time scales (PDT) are likewise offset.) The arrows mark the release time. Both charts show considerable signal enhancement at 14.1 MHz following the releases. The 7.175 MHz recording for the first release shows slight but definite enhancement while the same recording for the second release does not. Measurements from Ely are not shown. They produced entirely negative results. The enhancements shown are clearly due to the barium releases. They occur promptly at the time of the release and are of a magnitude that is much different from anything that precedes or follows them. The enhancements last about a minute before they gradually decay back into the ambient signal condition.

The noise or interference level was the principal limiting factor in the measurements at Santa Barbara and to some extent at Ely. The noise was probably due to distant thunderstorms or distant man-made sources and varied considerably from day to day. Additionally, ionospheric reflections of the signal transmitted from Tonopah effectively raised the background noise level of the receivers. Both receiving stations were intentionally

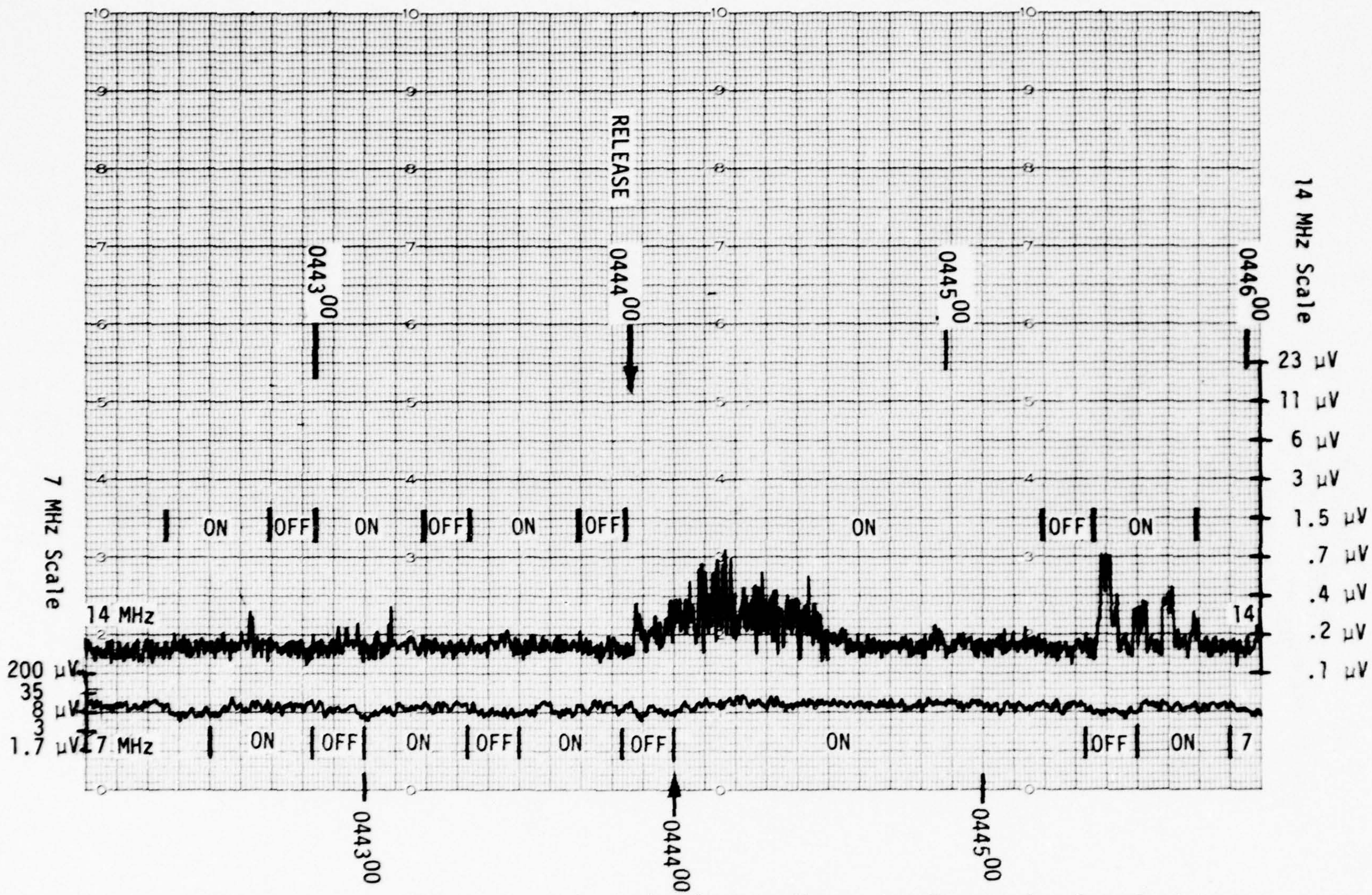

Figure 2. Strip chart recording of received signal strength tor two frequencies from Avefria I taken at Santa Barbara.

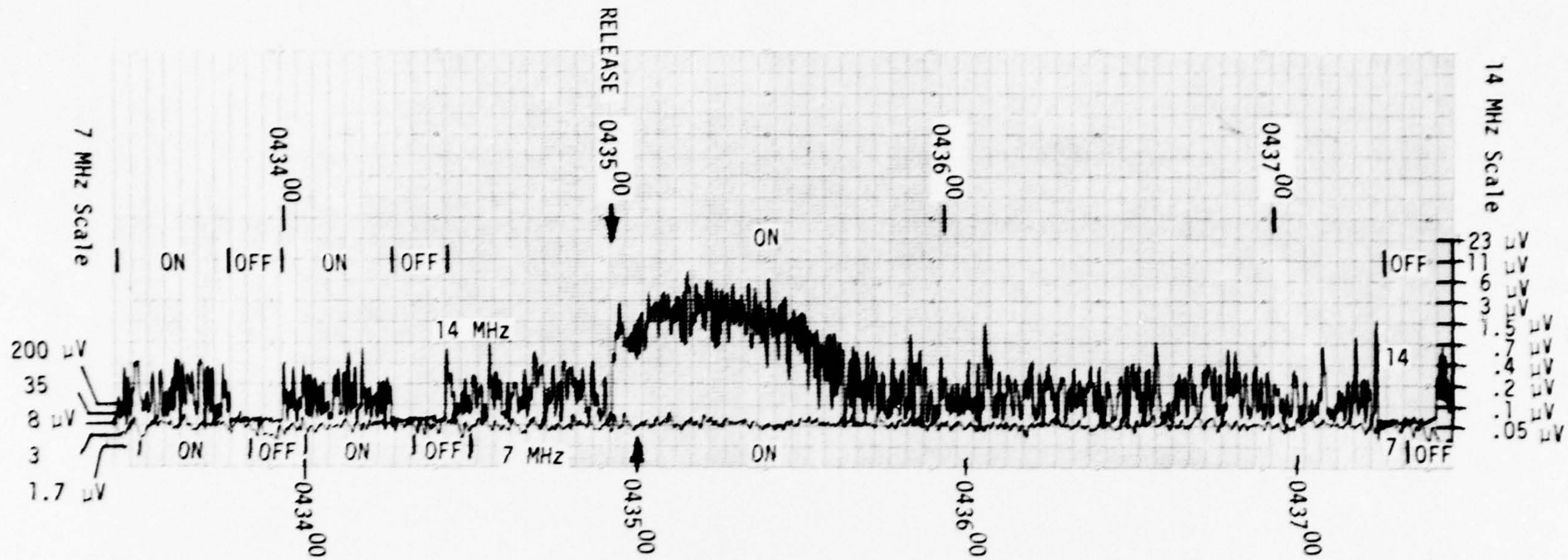

Figure 3a. Strip chart recording of received signal strength for two frequencies from Avefria II taken at Santa Barbara.

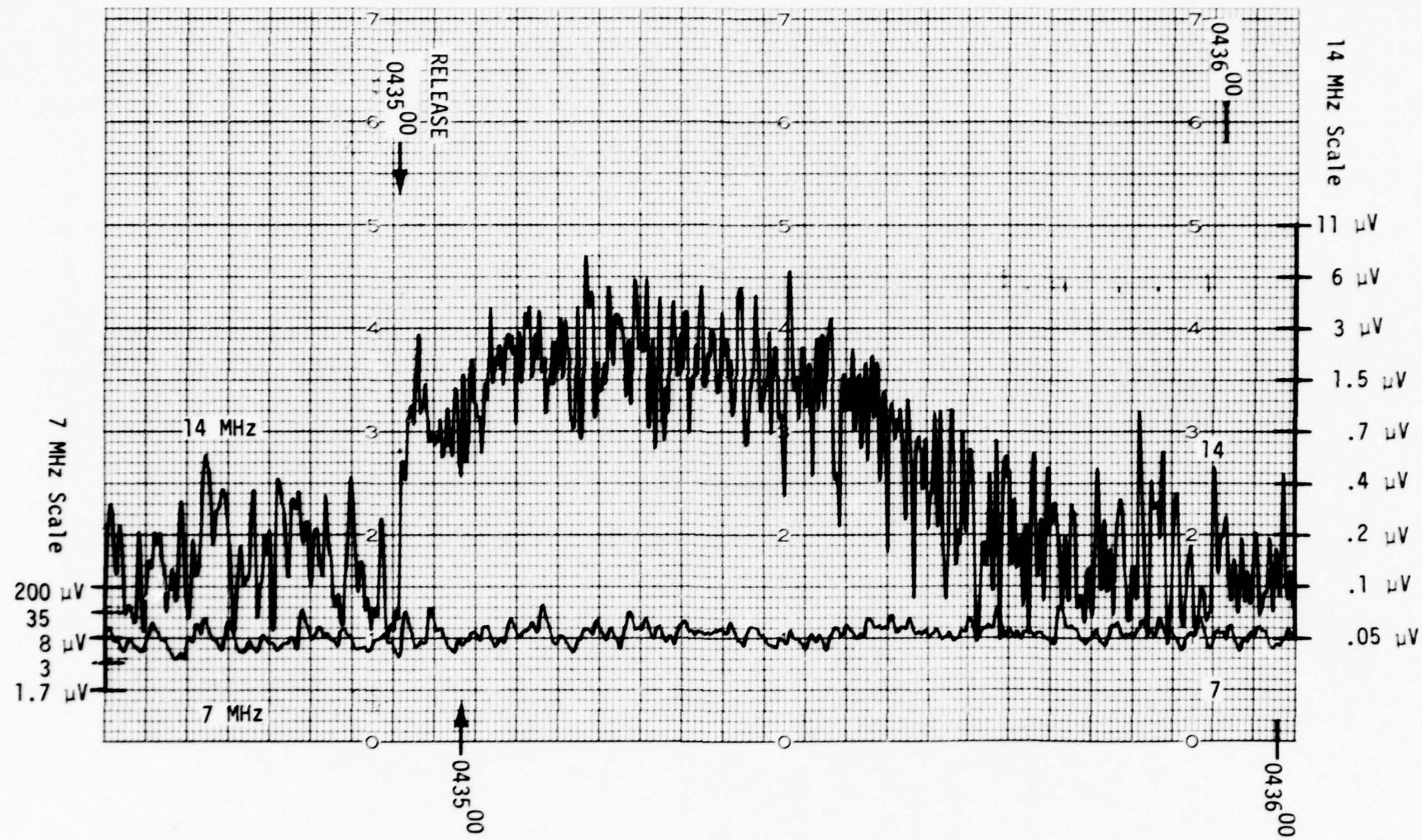

Figure 3b. An enlargement of that portion of the recording taken for a one minute interval beginning just before the release.

located far enough from the transmitting station so that ground wave transmissions were impossible but close enough so that normal sky wave communication was improbable. As it turned out, relatively weak signals did propagate, likely via ionospheric turbulence or sporadic E. Figure 4 shows the possibility of ionospheric scatter or turbulence supporting communication, and we further suppose that sporadic E may have been responsible.

Figure 3 shows a low noise level at 14.1 MHz and a relatively strong signal reflected from the ionosphere. The on-off pattern of transmission is clearly evident in the recording prior to the barium release. At 7.175 MHz the situation is just the opposite. The transmitted signal reflected from the ionosphere is hardly visible over the noise. In fact, the noise is so strong that it masks any enhancement that might be due to the barium release. Figure 2 shows a high noise level at 14.1 MHz that nearly masks the transmitted signal reflected from the ionosphere but shows the barium release enhancement. At 7.175 MHz the noise does not completely mask the transmitted signal. The enhancement due to the barium cloud is slightly visible.

The failure to see any enhancement due to the barium cloud in Ely is partly explained by the even higher noise levels encountered there. These occurred because the receivers did not have CW filters and were thus accepting a broader band of noise. The Ely station also suffered from relatively insensitive AGC circuits on the receivers. These AGC circuits did not respond to as low a signal level as those in use at Santa Barbara. The upper limits were obtained in Ely. However, the sensitivity of the station at Ely was adequate to detect signals of the strength which would be predicted on the basis of cross sections seen at Santa Barbara. The fact that the upper limits on Ely cross sections are less than those measured at Santa Barbara suggests a directional character to the scattering from the base of the striations and is discussed further in the data analysis section.

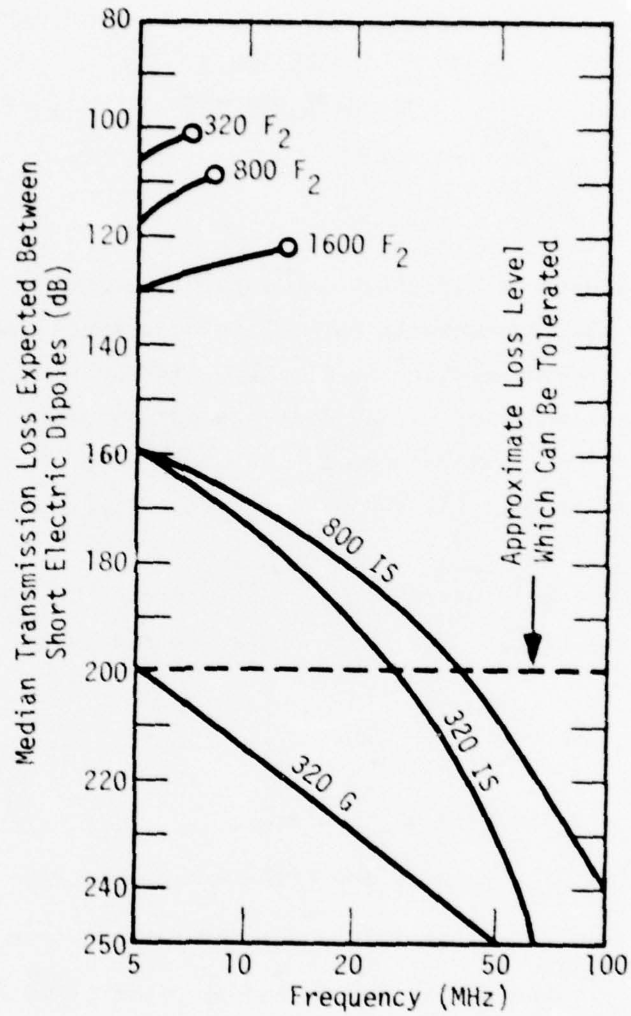

Figure 4. Transmission loss at midnight for typical transmission parameters. Distances are in kilometers and F_2, IS and G represent F_2 reflection, ionospheric scatter and ground wave modes respectively. (Taken from Figure 41 of Transmission Loss in Radio Propagation II, by Kenneth A. Norton, National Bureau of Standards, June 1959.)

SECTION 3
DATA ANALYSIS

While the strip chart recordings presented in Figures 2 and 3 clearly show the enhancements due to the barium releases and thus clearly establish that communication is possible off the base of striated barium clouds, further analysis is necessary to obtain reflection cross sections which allow comparisons between the various radio observations of this experiment and between the radio observations and optical data.

Figure 5 illustrates the basic setup. The power received by the base of the barium cloud to be reflected to the receiver is

$$P_B = \frac{P_T\ G_T}{4\pi\ R_T^2}\ \sigma \tag{1}$$

where P_T is the power transmitted

G_T is the gain of the transmitting antenna over isotropic

σ is the cross section of the barium cloud

and R_T is the distance from the transmitter to the barium cloud.

The power absorbed by a perfectly matched receiver is then

$$P_R = \frac{P_T\ G_T\ G_R\ \lambda^2\sigma}{(4\pi)^3 R_T^2\ R_R^2} \tag{2}$$

where λ is the radio frequency wavelength, $\lambda^2/4\pi$ is the effective area of an isotropic antenna and R_R is the distance from the barium cloud to the receiver. More properly, (2) should be written

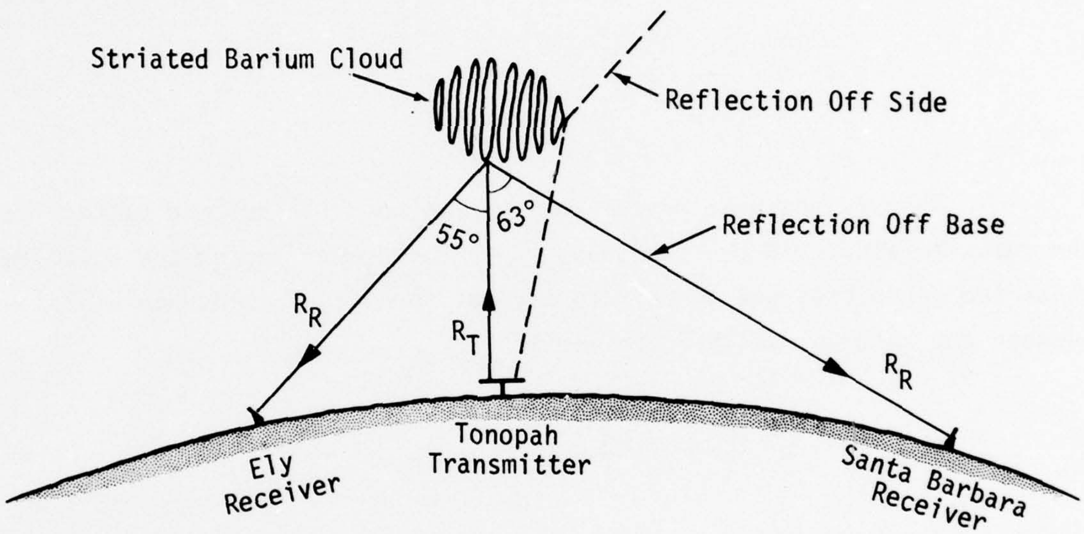

Figure 5. Schematic drawing of geometry of experimental arrangement for reflections off the base of a barium cloud (as viewed from the northwest).

$$P_R = \frac{P_T\ G_T\ G_R\ \lambda^2 \sigma}{(4\pi)^3\ R_T^2\ R_R^2} \cdot L_T\ L_R \tag{3}$$

where L_T and L_R take account of losses in the coaxial cable connecting the antennas with the transmitters or receivers. Solving (3) for σ gives

$$\sigma = \frac{(4\pi)^3\ P_R\ R_T^2\ R_R^2}{P_T\ G_T\ G_R\ \lambda^2\ L_R\ L_T} \quad . \tag{4}$$

What is measured by the receiver is not P_R but the voltage across the input terminals of the receiver, V_R. The proper expression which relates these two quantities and takes into account the slight impedance mismatch between the antenna and the receiver is

$$P_R = \frac{V_R^2}{Z_A} \left(\frac{Z_A + Z_L}{2Z_L} \right)^2 \tag{5}$$

where Z_A and Z_L refer to the impedances of the antenna and load (receiver) respectively. In our case,

$$Z_A = 73\ \Omega$$

$$Z_L = 50\ \Omega$$

so (5) becomes

$$P_R = V_R^2/48.25 \quad . \tag{6}$$

To apply Equation 6 to the data in Figures 2 and 3, we select the highest average voltage enhancement for each frequency and release. Tables 1 and 2 show the choices that were made.

Determining the antenna gains at the three stations turns out to be more difficult than might be thought because of the substantially unknown nature of the ground plane beneath the antennas. For all three stations it was a flat dry lossy ground of otherwise unknown nature. We assume it to be similar to that of Reference 4 and use those graphs reproduced in Figure 6. For the most part, the antenna patterns vary sufficiently slowly with look angle and antenna height that reliable values can be obtained. However, for the 14.1 MHz transmitting antenna during the first release, considerable uncertainty results from not knowing the effective height of the antenna. If the effective ground plane were just 2 meters below the surface then the antenna gain in the direction of the release would decrease by 4.5 dB or a factor of 3. For consistency and simplicity we have always assumed the effective antenna heights to be the actually measured values. In this one case, the assumption of a surface level ground plane could lead to cross sections that are low by a factor of about 3.

Line losses, including coax attenuation and VSWR losses, have been estimated using standard techniques given in Reference 5. These are generally small and are listed in Tables 1, 2 and 3.

At this point all of the quantities necessary for the solution of Equation 4 have been determined and are listed in Tables 1, 2 and 3. The results of cross section calculations in the various cases are given in Table 5.

In several cases actual cross sections are given and in other cases merely upper limits. The values for the first release at 14.1 MHz are labeled as less certain because of the uncertainty in the antenna patterns. They could be as much as a factor of 3 larger on this basis alone.

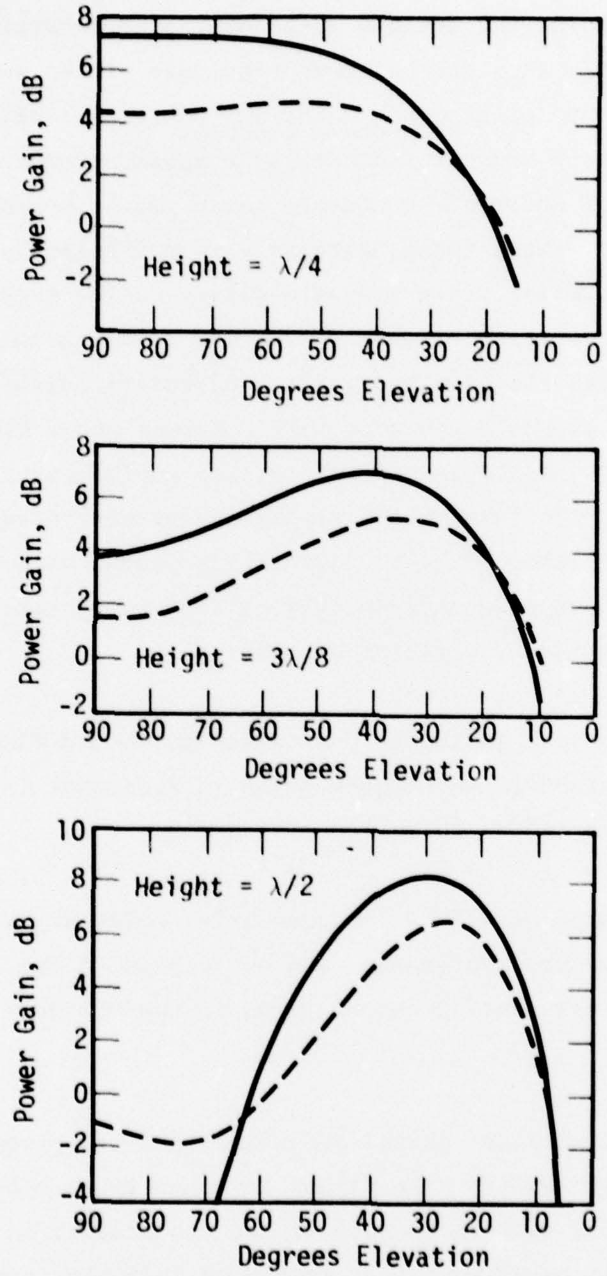

Figure 6. Broadside antenna gain of a horizontal half wave dipole at three heights. Solid line is for over salt water and dashed line is for over dry soil. (From Reference 4).

Table 5. Measured cross sections.

	Frequency (MHz)	Santa Barbara Cross Section (km^2)*	Ely Cross Section (km^2)*
AVEFRIA I	7.175	12	< 8
	14.1	.02**	< 4**
AVEFRIA II	7.175	< 21	< 8
	14.1	2	<.3

*The estimated uncertainty is ±5 dB or a factor of 3.

**These values may be low by an additional factor of 3, see text.

The estimated cross sections vary from .02 km^2 to more than 20 km^2. The larger cross sections are observed at the lower frequency as would be expected since a lower electron density is required to reflect a lower frequency. (A plasma density of 6.4×10^5 cm^{-3} has a critical frequency of 7.175 MHz, while 2.5×10^6 cm^{-3} gives a critical frequency of 14.1 MHz.) Furthermore, cross sections of this order agree well with photos taken from Santa Barbara. The characteristic dimension of the striations observed optically is about a kilometer in diameter. Depending on the number of striations and the shape of the striation base, one can arrive at expected cross sections from visual observations that are close to what we observed with the radio signals.

The cross sections observed at Santa Barbara can also be compared to some extent with the upper limits obtained at Ely. While the numbers are roughly comparable, those for Ely appear somewhat lower, especially for the

second release at 14.1 MHz. It appears that the cross section of the base of a barium striation has some (and perhaps substantial) directional character.

Another phenomenon, which is not accounted for in the calculations, can affect the result. Faraday rotation causes the plane of polarization of radio waves to rotate as they pass through the ionosphere. The total rotation, in radians, for a one-way passage through the ionosphere by a high-frequency signal is given by[6]

$$\Omega_F = \frac{2.36 \times 10^4}{f^2} \int_0^\infty (B\cos\theta \sec\chi) \quad N\, dh$$

where B is the local magnetic flux in Wb/m^2

θ is the angle between the radio wave normal and the magnetic field

χ is the angle between the wave normal and the vertical

N is the electron density

and f is the frequency (all in mks units).

Using the model ionosphere shown in Figure 7, the total rotation expected is close to 1 radian. The actual ionosphere could have differed in density by as much as an order of magnitude resulting in a similar variation in Ω_F. However the electron density profile of the cloud (unless absolutely sharp) will introduce additional rotation which will likely exceed 1 radian.

Whatever the degree of Faraday rotation, the net result would have been less (or equal) signal strength received in Santa Barbara and Ely because the transmitting station and both receiving stations used the same (horizontal) polarization. Consequently, the cross sections (including upper limits) given in Table 5 are potentially low. In other words, the bases of the barium clouds probably reflected more power than we observed. Of course, a slightly changing phase path in conjunction with $\Omega_F >> 1$ would lead to fading signals with a peak intensity equal to that for no polarization loss.

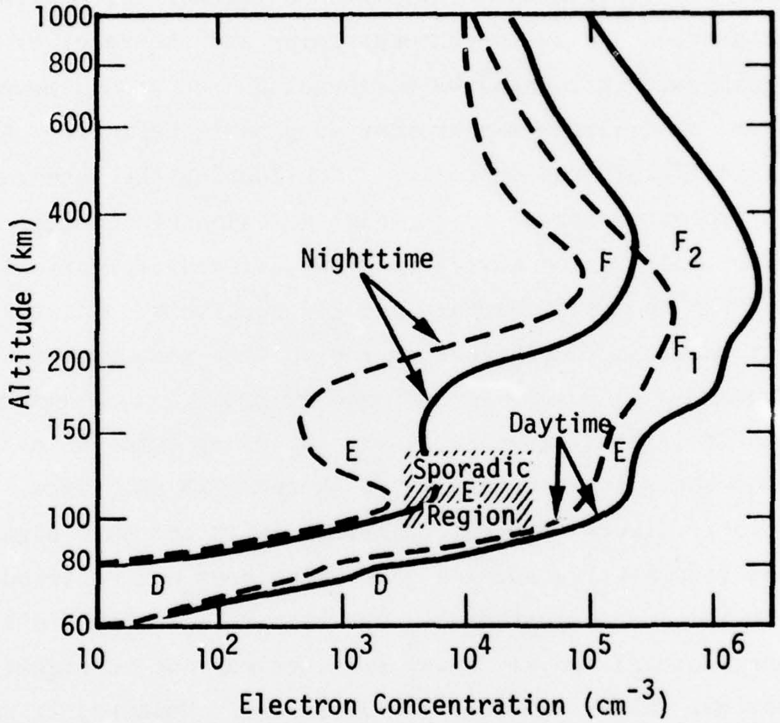

Figure 7. Typical ionospheric electron density profiles for day and night and for sunspot minimum (dashed) and maximum (solid). (Taken from Aerospace Environment chart, Air Force Cambridge Research Laboratories, New Bedford, Massachusetts, 1974.)

This experiment was designed primarily to show the existence of a propagation mode off the base of high-altitude striations. Detailed investigation of cross sections was a secondary consideration. As a consequence, some aspects of the experiment do not allow a clean error analysis. The primary uncertainties are in the antenna gains and the receiver calibrations. The antenna gains are influenced by surroundings and ground properties and so nothing short of a direct measurement of gain is reliable. A direct measurement is difficult and expensive. Considering the antenna patterns of Figure 6 a typical error of ±2 dB seems a reasonable estimate of gain error. Receiver calibration was carried out using different calibrated signal generators for the Santa Barbara and Ely receivers. Internal consistency checks suggest that the uncertainty of the voltage measurements is about ± 2 dB which translates into ±4 dB for the resulting cross sections. Total uncertainty in the stated cross sections, including both the antenna gain uncertainty and the voltage uncertainty, is about ±5 dB. Since the Santa Barbara and Ely receivers were not calibrated with the same signal generator, it is only the transmitting antenna gain which does not contribute to relative errors in the two measurements. The result is that the difference between the Santa Barbara and Ely cross sections may not be significant although the nominal values are somewhat different. However, it seems likely that the difference is real.

SECTION 4
DISCUSSION AND CONCLUSIONS

This experiment clearly establishes that radio communication between distant stations is possible off of the base of overdense structures created by a shaped charge barium release. Though radio signals do not come labeled as to what phenomena are actually causing reflection, the observations unmistakably point to this conclusion. First of all, the strong signal enhancements observed at Santa Barbara on 14.1 MHz and the small but definite enhancement at 7.175 are precisely correlated in time with the actual barium release. The enhancements are sufficiently prominent that they can be easily distinguished from any background noise or interference.

To determine that the barium plasma itself is causing the enhancements and not some other aspect of the release, we note the relatively large cross sections shown in Table 5. No other known process involved in the barium release could produce these cross sections and sustain them for the period they were observed. Metallic pieces of the rocket used to carry the barium to altitude have a far insufficient cross section. The shock wave from the shaped charge explosion could compress the nearby ionosphere for an instant and provide some enhanced signal. But this enhancement should die much faster than over a period of a minute. The only other reflecting medium created by the release is the barium plasma itself. This must have caused the signal enhancements observed. That striations were involved is shown by the many photographs taken by various observers including ourselves. As was planned, some of the barium plasma striated almost immediately upon release due to the shaped charge configuration of the release.

Because only a portion of the ionized barium cloud striated in the first minute, it is unclear whether the striated or unstriated region or both were responsible for the enhancements observed. The nominally different cross sections for different directions suggest an unsymmetrical base shape consistent with striations and more difficult to achieve with an unstructured plasma. However, given the relative uncertainties in the measured cross sections, it is conceivable that these cross sections were not significantly different. Thus, while striations were unquestionably present, the data do not prove that all observable enhancements came solely from structured, as opposed to unstructured, plasma.

The development of the scattering region is suggested by a closer look at the strip chart recordings in Figures 2 and 3. The 14.1 MHz case shows an immediate strong enhancement of the received signal at the time of release followed by a gradual increase in that signal over a period of about 15 seconds as more barium becomes ionized in the early morning sunlight. A maximum enhancement is reached when the production of plasma slackens and diffusion along the field lines gradually begins to reduce the size of the region which is overdense to 14.1 MHz. The existence of plasma overdense to 14.1 MHz for a period of about 30 seconds was predicted prior to the release.[7] The larger cross section observed for 7.175 MHz is to be expected because the striations should have larger regions that are overdense to 7.175 MHz than to 14.1 MHz.

The deep fades observed in the enhanced signal are not completely understood because they could have more than one origin. Changes in the Faraday rotation of the horizontally polarized wave could produce polarization fading. A layer of sporadic E could mask the signal reaching the barium striations or returning from them. The striations themselves could mask one another, thereby alternately increasing and decreasing the observed cross section. However, the fact that the fades during the enhancement show about the same periodicity as the signals received prior to the release (see

Figure 3, 14.1 MHz) suggests the possibility that the fading is ionospheric in origin. Fading due to sporadic E sometimes shows a character similar to that observed.[8]

The upper limits on cross sections obtained by the Ely receiving station suggest, but do not conclusively prove, that the cross section for radio wave scattering from the base of barium striations has a directional dependence. It would be interesting in the future to look into this directional dependence more closely. More definitive results would tell us something about the shape of the base of barium striations.

Another topic that needs closer study is the precise applicability of these results to the nuclear case. While the observations presented here are obviously pertinent, the generalization to the nuclear case requires careful thought.

Finally, it should be emphasized again that the reflections observed from the barium clouds had to come from the base of those clouds. Side reflections were not possible for the arrangement of stations used.

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